SEA RESCUE MISSIONS MUST NOT SLOW DOWN

Johan Ullman M.D. Ullman Human Design Gothenburg SWEDEN

SUMMARY

High-speed boats generate significant impacts slamming against the water surface. These impacts are transferred into the bodies of people on board causing not just fatigue, but also have the potential to cause severe injuries, both acute and cumulative. Higher boat speeds and higher waves increase the amount of energy transferred to human body. No other professional environment exposes workers to vibration and impacts of the same magnitude.

To protect workers from dangerous exposure to shock and vibration the EU Parliament and Council have passed EU Directive 2002/44/EG "**on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents - vibration**".

Applying this directive in high-speed boat environments can result in unreasonable restrictions for patrol and rescue operations and military training.

Potentially life-threatening impacts can still occur without exceeding the exposure limits stated in the directive. Solid data cannot ethically and practically be obtained to determine safe levels of exposure.

The directive needs to be adapted for high-speed boat applications regarding exposure limits, as well as methods of measuring exposure**.**

The directive states that, in the mean time, employers are obligated to seek new solutions, and implement the best available routines and technologies, in order to reduce the exposure to potentially dangerous shock and vibration exposure.

1. INTRODUCTION

Among operators of high-speed boats impact-induced injuries are so common that many professionals consider them a natural part of life. Most common are injuries to the back, neck and extremities.

Thus it is absolutely necessary to control shock and vibration exposure. This is why the EU commission has formulated a shock and vibration directive for all industries, which restricts the exposure to whole body chock and vibration.

2. HEALTH RISKS & HIGH-SPEED CRAFT

Recent studies have shown that in professional organisations high-speed boat crewmembers report back neck and leg injuries on duty in up to over 50%. Few other, if any, occupations are associated with the same risks of injury.

Continuous whole body vibration (WHB) is known to be associated with adverse health effects and discomfort. WHB causes fatigue over time and also seems to predispose for tissue injuries. Thus it is relevant to limit the occupational exposure.

Amongst operators of high-speed craft the main concern is not the continuous vibrations, but the slamming induced impacts, the magnitude of which can reach levels of 10 to 20g.

Vertical impacts are known to cause disk herniations and vertebral fractures. Repeated vertical impacts are known to cause wear of joint cartilage in knees and ankles.

Compression forces and shear forces acting on the spine can cause spinal injury. The spine is more vulnerable to shear forces than pure compression. Therefore are horizontal accelerations in vibration standards multiplied by a factor 1.4.

In Europe there is a consensus regarding a dose response ratio between amplitude of impacts and the risk of injury.

Other factors that influence the risk of injury are duration of an impact and the speed of onsets of the impact. These parameters can be measured.

Several individual factors are also relevant, such as age, history of exposure, daily duration of exposure, physical fitness, mental awareness, body posture and posture of spine under exposure.

Studies comparing impact at the deck of high-speed boats with impacts registered from the lumbar region of the human body have shown significantly higher peak values on the body of standing subjects. It has also been shown that traditional seats, with or without suspension, have a capacity to amplify the impact levels as compared to the levels measured off the deck.

Repeated flexion-extension exposure of the spine has been shown to be is associated with a risk for disk herniations.

3 COPING WITH IMPACT

Experienced high-speed vessel operators know that when the impact levels rise, so does the crew. The reason is that impacts hurt more when you sit.

There are two main reasons why vertical impacts hurt more on the seated person than on the standing. One is that in normal sitting the spine is C-shaped and not optimized to withstand vertical impact. This is due to the

fact that the pelvis on a seated person is tilted backwards so that the spine has to be bent forwards to maintain balance. The C-shaped spine is more vulnerable than the normal S shaped spine maintained in standing. This is because the vertical impact here causes more deflection than on an erect S-shaped spine.
The seated position also puts the centre of gravity of the head forward of its supporting structures, which increases the risk of head-jolt as compared to the erect position of the spine.

Fig 1 Normal sitting bends the spine and makes use of leg muscles unfeasible.

The other reason is that a standing person can, to some extent, use the legs to damp out high impacts.
Traditional sitting makes use of leg muscles to take up significant amounts of energy practically impossible.
Standing up at impact, the posture normally chosen by crewmembers, is not however, the obvious solution it might seem, to reduce impact on the spine and neck.
The capacity to absorb impact on the legs is depending on muscular strength, physical shape and is limited by muscular fatigue. The physical work required in high seas is similar to that of downhill skiing.

4 EU DIRECTIVE & HIGH-SPEED CRAFT

4.1 COMPLYING WITH THE DIRECTIVE

Complying with the directive can restrict procedures of sea rescue operations to such an extent that the efficiency of normal missions could be significantly reduced.
Military personnel might not be allowed to train for procedures that they will be facing under deployment.

The main problems with applying the new EU directive on high-performance watercraft are besides, preventing task forces from performing their tasks, that the limits stated in the directive have limited significance on the actual exposure to dangerous shocks and vibrations.

Dangerous exposure can be at hand without coming close the limit values stated in the directive. Boat operators and crewmembers could be exposed to impacts large enough to cause acute and permanent injury, without exceeding limits stated by the directive.

On the other hand, experienced operators and crews can cope with extreme impacts given the right conditions. This means that e.g. during rescue operations the limits of the standards can be by far exceeded without putting the crews at risk. Based on reports from experienced operators normal procedure at sea are carried out with exposure level well beyond the limits of the directive.

One major problem with the directive is that no validated injury criteria exist. Experimental data are not available, to actually calculate the risk of injury in relation to impact levels. There is also no method by which such data could be acquired. Experiments resulting in actual injuries can never be accepted.
The limits have been calculated based on experiments made on spine segments from human cadavers. The mechanics of the living spine is quite different from that of dead tissue.
There is still no solid scientific evidence to support the limits stated will prevent injuries caused by whole body impact. This however is a minor problem.

The major problem is how to reduce the impacts at sea to reasonable levels, and to determine what is reasonable.

4.2 MEASUREMENT METHODS

The measurement methods specified in the EU directive are not fully relevant to assess the exposure to whole body vibration and the impact, nor the risk of injury. It is stated that vibration shall be measured at the surface of the seat a person is supposed to sit on.
As operators rarely sit at impact, data collected from the seat, at times when the worst exposure occurs, will have very little or no correlation to the energy transmitted to the torso, or relevance for quantifying harmful exposure.

Impacts of the magnitude generated by high-speed boat can also make a seated person bounce up and down. Alternatively the subjects will choose not to sit on all, or try to rise from the seat intermittently, just like a horseback rider, as a method to reduce impacts.

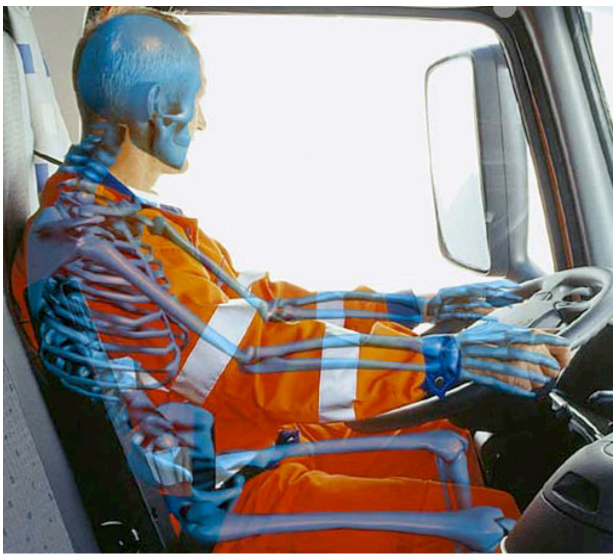

Fig 3. *Land vehicles expose operators to continuous vibration. Even reclined seats put strain on neck.*

The directive is based on standards created to quantify and limit adverse health effects, specifically on the human spine, from exposure to continuous whole body vibration, primarily such generated by land vehicles.

Off-road land vehicles and forestry machines expose operators to high accelerations, but normally not nearly as extreme as those high-speed boats produce.

The directive does not account for differences in body posture. It just assumes that exposed subjects are seated at all times.

Exposure on high-speed boats differ from exposure on land also in the respect that impacts are less predictable and vary very much in character. Especially the vertical components can be extreme and always come in combination with horizontal components.

The ISO Standard 2631:1 has focused on predicting back injuries caused by cumulative trauma/ exposure to continuous vibration. It is not useful in predicting the risk of back and neck injury caused by discrete impacts. Nor is it useful to predict extremity injury.

4.3 CALCULATION METHODS

The exposure is calculated to quantify energy transmitted to the torso of the human body. The rms (root mean square) method chosen for the ISO standard and the EU directive can be relevant to assess cumulative exposure to continuous whole body vibration, but not to assess exposure to transient whole-body impacts.
The rms method calculates mean exposure over time. It is not capable of accounting for sudden impacts of high amplitudes.
By using this method a single impact of extreme and potentially dangerous magnitude can be averaged out and will not necessarily indicate dangerous exposure.
Thus a person can be subject to discrete impacts, high enough to cause acute tissue damage such as herniation of intervertebral disks and fractures of vertebral bodies, without exceeding the exposure limits of the directive. The rms method can be used to come up with the same exposure for a lethal fall from 10 m as for a moderate continuous vibration during period of time.

There is a positive dose-response ratio regarding impact-induced injuries. The more energy that is transmitted to the human body by an impact and shorter the time for this transmission the greater the risk of injury.
This has been proven in car crashes, fighter aircraft ejections, parachuting etc and hence does not need experimental proof to be accepted for marine applications.
The shorter the time for absorbing the energy the higher is the peak acceleration. The higher the acceleration is, higher are the compression forces.
Harmful impact exposure can be reduced by lengthening the time period under which the human body takes up energy from the boat. This method of reducing peak accelerations will however not necessarily yield lower exposure values as defined in the directive.

5 DEROGATIONS

The authors of the directive have realized that complying with the maximum tolerable exposure values can create serious problems for marine applications.
Derogations will however only be accepted after all measures have been taken to reduce the exposure levels, technological and organisational. It is stated that it is the employer's responsibility to provide the best available solutions to reduce harmful exposure.

"*Member States may, in the case of sea and air transport, derogate from Article 5(3,) in duly justified circumstances, with respect to whole-body vibration where, given the state of the art and the specific characteristics of workplaces, it is not possible to comply with the exposure limit value despite the technical and/or organisation measures taken*."

6 REDUCING HARMFUL EXPOSURE

In recent years significant technological development has been done in order to reduce harmful motion exposure. One such project has become standard in a number of organisations, e.g. Swedish Coast Guard, Dutch and Swedish Sea Rescue Institutions.
The concept utilises the human biological shock mitigation system in conjunction with a semi-active mechanical spring and damper system.
Straddle seats allow the crew to remain seated maintaining the natural S-shape of the spine. The natural reaction is to rise slightly from the seat prior to impact, while still maintaining bent legs, so that the muscles on the front-side of the thighs and the back-side of the calf can act as shock absorbers. This is analogue to the natural behaviour of horseback riders, and motocross riders. The system has been proven to significantly reduce the impact measured at back on the human body.

Bolster seats are padded horseshoe shaped lateral and dorsal supports, designed to keep a standing or semi-standing person in place. These are common in offshore racing and are used in some high-speed patrol boats.

Neither of these systems that can be validated using the measurement methods in the EU directive, as operators either stand or constantly change between standing and sitting

7 MEASURING IMPACT ON THE BODY

A new method has been developed to measure whole body impact and vibration in field studies and sea trials. To acquire relevant data the acceleration is measured on the human body itself.

The accelerometers are attached to stiff elements contained in an elastic girdle, which is elastic in only one direction, around the body, and stiff in the other. Its stiff elements are oriented parallel to the main axis of the torso. The girdle is applied closest to the body, so that it is in contact with the skin over the upper part of the pelvis and the lower part of the thorax.

Fig. 2. Girdle keeping accelerometer fixed on back.

The method has been validated against the standard method, where accelerometers are attached to pins inserted into the spinous processes of lumbar vertebrae. It has good correlation in frequencies up to 16 Hz.
This method is useful regardless of whether the subject is standing or sitting.

8 PAIN AS INDICATOR OF RISK

As valid injury criteria do not exist, other indicators of dangerous exposure are needed, to assess and limit the risk of injury.

The best predictor of dangerous impact exposure is the human body itself. Discomfort is a sign of potentially harmful exposure, severe discomfort indicates harmful exposure and pain is an efficient indicator dangerous exposure.

Acute injury to the body very seldom occurs without the sensation of pain.

Cumulative trauma can cause injuries without pain, but rarely without discomfort. Such injuries aggravate over time with continued exposure. Eventually even cumulative trauma can cause tissue damage and chronic pain problems.

Consequently the most valid indicators of harmful exposure are physiological: pain and discomfort experienced in relation to exposure.

9 CONCLUSIONS - RECOMMENDATIONS

The common objective for the authors of the EU directive and the scientists working in the field of whole body shock and vibration is to create the safest possible working conditions for high-speed boat operators, without impairing efficiency of marine operations.

In order to accomplish this, more research is necessary, as is the adaptation of the EU directive to high-speed craft operations

9.1 COLLECT DATA FROM BOATS AND CREWS

It is desirable to establish which impact levels and characters are associated with onset of pain and discomfort and which are associated with acute injury.

This could be done by continuous recording of impact data from boats and preferably from bodies/torsos of the crewmembers, linked with registration of subjective pain and discomfort assessments. When relations between impact levels and onset of pain and discomfort are established, it would be possible to create better recommendations for exposure limits

9.2 USE PAIN AS INDICATOR

A widely accepted, not to say ancient, method of reducing the risk of injury is to avoid painful exposure. Pain is physiologically an indication of dangerous exposure and can well be used as an indicator of such.

9.3 LOG EVENTS CAUSING PAIN AND INJURY

Crewmembers should be required to report pain or discomfort when it occurs. And records of speed and sea state should be done at these events as well as when injuries occur. If possible relate such events to simultaneous acceleration data

9.4 DEFINE OPERATOR'S RESPONSIBILITY

Operators should be required to make sure that pain or discomfort does not occur. Inexperienced crewmembers can, for obvious reasons, not be expected to report spontaneously.
People with history of back problems should not be working onboard high-speed craft.

9.5 MEASURE WHOLE-BODY IMPACT ON THE HUMAN BODY

The method that so far has shown the best correlation with measurements from the vertebrae is the method where accelerometers are mounted on girdles or ”kidney belts”. This method measures the accelerations affecting the human body/torso regardless of posture, sitting or standing.

9.6 ACCEPT SUBJECTIVE EXPOSURE ASSESSMENTS AS VALID.

The best criteria presently available to limit dangerous exposure are the subjective evaluations of the operators and crewmembers.
If they say it hurts, it most probably does.
If they say it feels good, it most probably is.
No one is better suited to determine what works and what does not, than those who are exposed onboard.

REFERENCES

For references see: **www.ullmans.com/eudirective/refs**

Johan Ullman M.D. is a specialist in Intensive Care and in Occup. Medicine and a Captain in the Swedish Navy. He has done research in the field of whole-body vibration since 1990 and has developed methods for measuring, and reducing shock and vibration exposure on high-speed craft.